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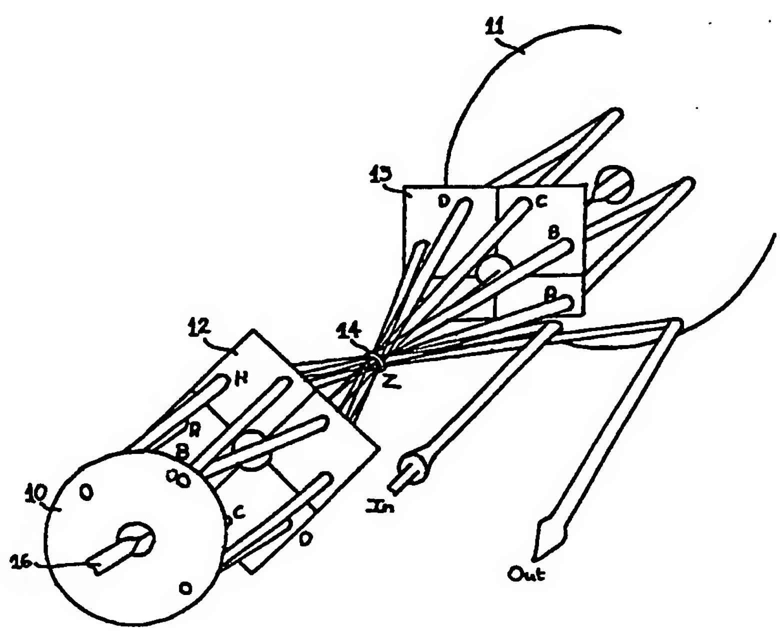

(57) Abstract

A multiple pass optical system has two plane mirrors (10, 11) opposing one another with two biprism elements (12, 13) located in between. The biprism elements (12, 13) are arranged to define in combination with the plane mirrors (10, 11) a plurality of beam paths having a common point of intersection (2). In this way with a minimum number of optical elements a system is provided with angularly multiplexed beam paths which spatially overlap in one plane.

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MULTIPLE PASS OPTICAL SYSTEM

The present invention relates to a multiple pass optical system and particularly but not exclusively to a multi-pass laser amplifier.

There a number of situations in which it is desirable to pass a beam of light, be it ultraviolet, optical or infrared, through a given device many times and by so doing greatly reduce the cost of the system and increase the space efficiency. In order to do so, however, any tendency for the beam on different passes to become coupled must be minimised. Known multi-pass optical systems generally rely on multiple mirrors requiring very careful alignment and are consequently costly, highly complex, permit only narrow bandwidth operation and can be unreliable as a result of the system sensitivity to alignment of the many optical elements.

The present invention seeks to overcome the disadvantages with known systems and to provide a simple but effective multiple pass optical system capable of operating with both narrow and broad bandwidths.

The present invention provides a multiple pass optical system comprising an opposing pair of reflective optical elements and first and second refractive optical elements located between the reflective optical elements and arranged to direct a beam of light along at least two paths having a common point of intersection, each of the paths describing a different azimuth angle with respect to a plane of symmetry containing the axis of the optical system.

In this way, with the present invention a beam of light may pass repeatedly through the same spatial point in the optical system along various paths with the light following any one of the paths remaining substantially uncoupled from the light following any other of the paths. Preferably, an amplifier is provided at the common point of intersection. Also the amplifier may be endpumped by directing pump beams along the optical axis from either end of the system.

Ideally, the reflective optical elements are plane mirrors positioned substantially perpendicular to the optical axis of the system. Also, preferably the refractive optical elements are double biprism devices.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a multiple pass optical system in accordance with the present invention;

Figure 2 is a perspective beam diagram for an eight pass amplifier in accordance with the present invention; and

Figure 3 shows in section the eight pass amplifier of Figure 2.

The multiple pass optical system shown in Figure 1 includes only two reflecting optical elements 10, 11 at opposing ends of the system. No additional reflecting optical elements are required. The reflecting optical elements 10, 11, which preferably are plane mirrors, are parallel to one another and normal to the axis X of the system. The multiple pass optical system also includes two refractive optical elements 12, 13 located between the two mirrors 10, 11 and either side of a common point of intersection Z of the beam path through the system. The two optical elements 12, 13 are purely refractive, have no optical power and are based on the biprism. Where the optical system is being used in combination with an amplifier 14, the amplifier 14 is positioned at the point of intersection Z of the beam paths.

The refractive optical elements 12, 13 or biprism elements determine the beam path through the optical system and hence the number of passes through the point of intersection Z between the input and output of the optical system. The biprism elements 12, 13 are arranged so that the beam path does not pass through the axis X of the optical system except at the common point of intersection Z.

In Figure 2 the beam path through an eight pass amplifier is shown. To achieve eight passes through the point of intersection Z, each of the refractive optical elements 12, 13 is a double biprism. The double

biprism consists of an orthogonal pair of biprisms having equal angles. The pair of biprisms may be made as a low aspect-ratio pyramid, as two biprisms on opposite faces of the optical element or as four half size biprisms. The double biprisms are positioned either side of the point of intersection Z, within the two mirrors 10, 11, and are mutually orientated azimuthally at 45°.

A beam In which enters the optical system and passes through the point of intersection Z, at which an amplifier 14 is located, meets the first of the double biprisms 12 at a point H on the double biprism. The beam is refracted by the double biprism 12 and is then reflected by the plane mirror 10 to point A which is in the next quadrant of the double biprism 12 but is equidistant from the axis X. The beam is again refracted and passes through the amplifier 14 to an equivalent point A on the second of the double biprisms 13. A similar route is now followed by the beam via the plane mirror 11, to a point B in an adjacent quadrant of the second of the double biprisms 13 and thence via the amplifier to a point B marked in dotted lines on the first of the double biprisms 12 at an orientation of 90° to point H. This beam path continues in the same manner until after eight passes through the amplifier 14 the beam arrives at a position from which further refraction and reflection would result in the beam rejoining the original path to point H on the first double biprism 12.

All of the paths followed by the beam between the double biprisms 12, 13 and the point of intersection Z are at a fixed angle to the optical axis X of the system and in consequence the paths lie on the surface of a cone the apex of which is the intersection Z. The points of intersection of the beam with each of the double biprisms describe the apexes of an octagon.

The input beam In and the output beam Out are introduced into and emerged from the optical system respectively via a corridor 15 through the second of the double biprisms 13. In its simplest form the corridor 15 is provided by removing an edge portion from the double biprism

13. The resultant output beam is substantially decoupled from the input beam. In Figures 2 and 3 the input and output beams In, Out are shown reflected off one of the end mirrors 11.

By appropriate selection of the refractive optical elements 12, 13 different numbers of passes through the optical system may be achieved. For example, for a sixteen pass system, each refractive optical element consists of two double biprisms with all equal angles, mutually orientated at 45°. Each pair of double biprisms has a relative orientation of 22.5°. The numbers of passes in each case may also be doubled by retroreflection.

With the optical system described the alignment of the two end mirrors is straightforward and the only critical adjustment is the tilt of the mirrors. It will be apparent that the number of optical elements has been reduced in comparison to conventional systems and the number of mirrors, in particular, minimised. This enables a more efficient use of space and maximises the bandwidth with which the system can be operated. Furthermore the optical system may be operated over a broad range of beam widths.

In addition, unlike known systems, the beam path through the optical system at no time extends along the axis X and only intersects the axis at the common point of intersection Z. This means that an amplifier located at the point of intersection Z can be pumped 16 from both ends through central holes provided in the optical elements of the system, as shown in Figures 2 and 3.

In Figure 3 a titanium sapphire amplifier 14 is positioned at the point of intersection Z of the beam path. Each ray in this diagram represents two routes between the optical elements and the amplifier 14. The pump beams 16 for the amplifier are shown along the axis of the optical system. Unlike other known systems this optical system may also be used with flashpumped amplifiers such as a Nd:glass amplifier as well as laser pumped amplifiers like the Ti:sapphire amplifier mentioned above.

Alternative arrangements of the optical system and in particular different optical elements are envisaged. For, example, instead of biprisms programmable refractive arrays may be employed and/or alternative refractive elements. In all cases, however, the optical elements are arranged so that the beam paths in different passes are angularly multiplexed and spatially overlapped in one plane.

CLAIMS

1. A multiple pass optical system comprising an opposing pair of reflective optical elements and first and second refractive optical elements located between the reflective optical elements and arranged to direct a beam of light along at least two paths having a common point of intersection, each of the paths describing a different azimuth angle with respect to a plane of symmetry containing the axis of the optical system.

2. A multiple pass optical system comprising first and second refractive optical elements positioned either side of a common point of intersection of beam paths and only two reflective optical elements located outside of the first and second refractive optical elements and opposing each other, each of the refractive optical elements having a plurality of refractive sectors with each sector defining in combination with one of the reflective optical elements a respective beam path, with the beam paths of all the sectors of each of the refractive optical elements lying on the surface of a cone the apex of which is the common point of intersection.

3. A multiple pass optical system as claimed in either of claims 1 or 2, wherein the reflective optical elements are plane mirrors arranged normal to the optical axis of the system.

4. A multiple pass optical system as claimed in any one of claims 1 to 3, wherein the first and second refractive optical elements are purely refractive.

5. A multiple pass optical system as claimed in claim 4, wherein the first and second refractive optical elements are first and second biprism elements.

6. A multiple pass optical system as claimed in claim 5, wherein each of the first and second biprism elements comprises an orthogonal pair of biprisms having equal angles, with the first and second biprism elements being mutually orientated azimuthally at 45° thereby defining eight

substantially uncoupled beam path passes through the system.

7. A multiple pass optical system as claimed in any one of claims 1 to 6, wherein there is further provided an output corridor through the second refractive optical element in the form of a cut away portion.

8. A multiple pass optical system as claimed in any one of claims 1 to 7, wherein there is further provided an amplifier at the common point of intersection.

9. A multiple pass optical system as claimed in claim 8, wherein apertures are provided in the reflective optical elements and the refractive optical elements along the optical axis of the system whereby pump beams may be directed along the optical axis of the system to the amplifier.

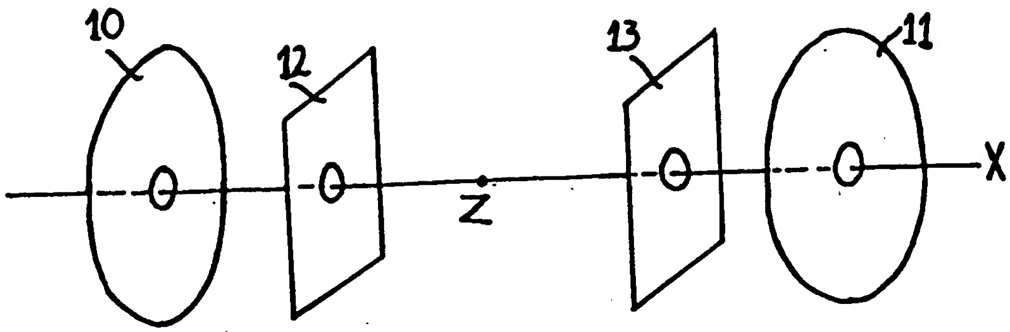

Figure 1

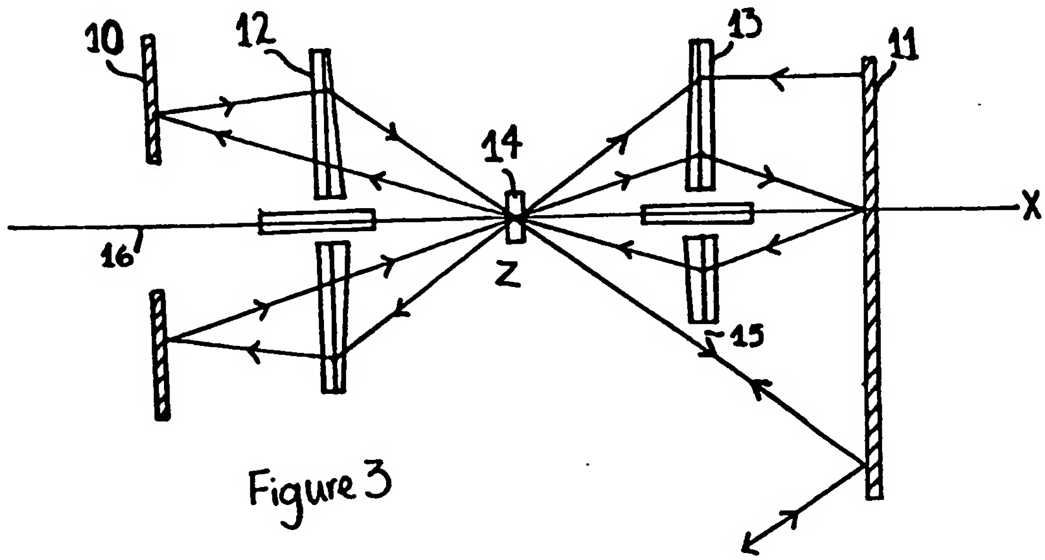

Figure 3

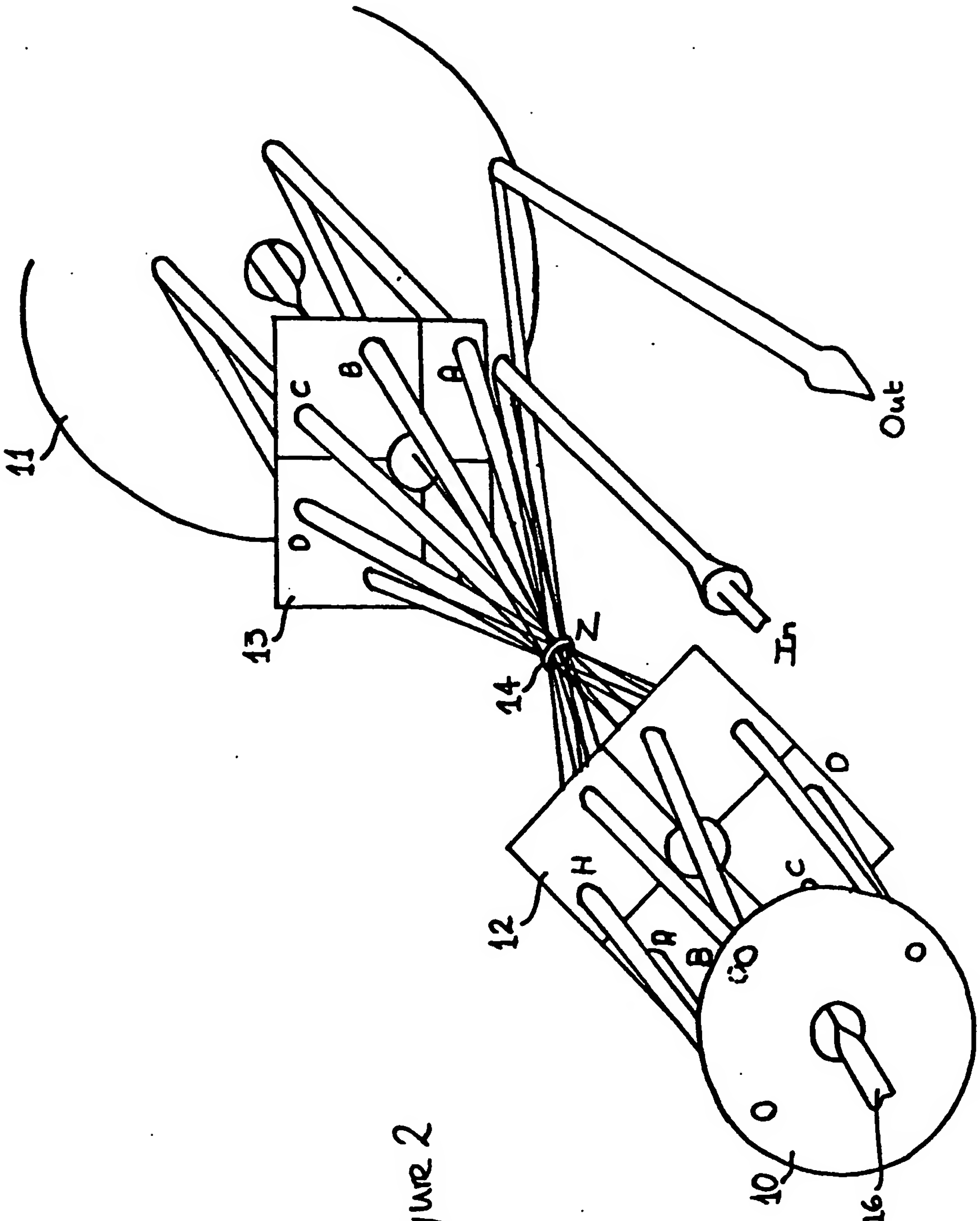

Figure 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/02085

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01S3/23 H01S3/094 G02B27/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01S G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE,A,30 36 656 (SIEMENS AG) 13 May 1982 see figure 1 ---	1,3
A	APPLIED OPTICS, vol. 30, no. 30, 20 October 1991, pages 4365-4367, XP000235547 MING LAI ET AL: "TRANSVERSELY PUMPED 11-PASS AMPLIFIER FOR FEMTOSECOND OPTICAL PULSES" ---	1,7,8
A	OPTICS LETTERS, 1 SEPT. 1993, USA, vol. 18, no. 17, ISSN 0146-9592, pages 1420-1422, XP000388158 PLAESSMANN H ET AL: "Multipass diode-pumped solid-state optical amplifier" --- -/--	1,8,9

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 November 1996	06.12.96

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Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 6, no. 5, 1 May 1994, pages 605-608, XP000446972 OLSON T E ET AL: "MULTIPASS DIODE-PUMPED ND:YAG OPTICAL AMPLIFIERS AT 1.06 MUM AND 1.32 MUM" -----	1,7-9

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A-3036656	13-05-82	NONE	